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DESIGN AND DEVELOPMENT OF HELICOPTER TRANSPARENT ENCLOSURES,(U)
APR 76 J H MCGARVEY, B F KAY

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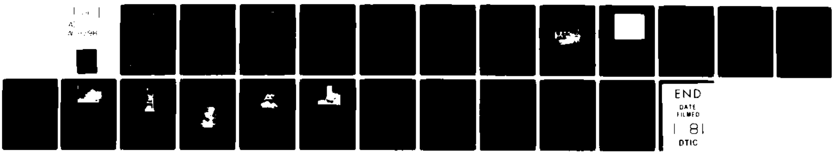

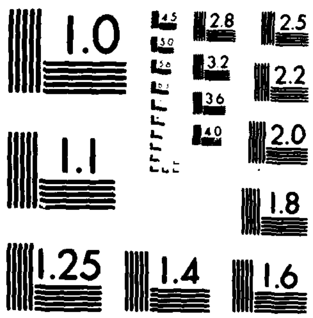

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DESIGN AND DEVELOPMENT OF HELICOPTER TRANSPARENT ENCLOSURES

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DESIGN AND DEVELOPMENT OF HELICOPTER TRANSPARENT ENCLOSURES

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ABSTRACT

Sikorsky Aircraft is currently engaged in a program sponsored by the U. S. Army Air Mobility Research and Development Laboratory to develop design, acceptance and test criteria for helicopter transparent enclosures. In addition, a comprehensive Helicopter Transparent Enclosures Design Handbook will be prepared. The effort is being accomplished in three major tasks:

* Establishment of Preliminary Criteria
* Verification of Criteria by Analysis and Test
* Preparation of Design Handbook

In general, criteria shall be substantiated using published data and historical acceptance. Where there is a lack of criteria, or where conflicting criteria exist, analysis and tests are being performed. Emphasis is placed on structural substantiation methods and the airframe/transparency interface.

Specific tasks that have been completed or are in progress include the following:

Windshield endurance tests are being performed in a manner intended to duplicate actual service conditions. The tests are being conducted with several types of structural loading applied to different windshield types, while subjected to various environmental conditions. Suitable instrumentation is used to determine critical loading combinations. The actual load spectrum used for these tests are based on typical utility helicopter mission profiles.

A NASTRAN (NASA STRuctural ANalysis) finite element analysis has been performed to determine the applicability of this type of analysis for helicopter cockpits. Finite element analyses can more accurately predict the internal stress distributions in complex structures, which can result in potential weight savings and improvements in component reliability. The analyses performed in this study showed that stresses induced in windshields from fuselage wracking can be significant.

As abrasion has been the number one cause for helicopter transparency replacements, a series of tests were conducted to enable simulation of the various forms of abrasion in the laboratory. The tests were conducted on glass, acrylic and polycarbonate, with the acrylic and polycarbonate materials with and without abrasion resistant hardcoats.

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21 AUG 1978

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6. ORIGINATOR'S DOCUMENT TITLE Design and Development of Helicopter Transparent Enclosures		7. DOCUMENT TYPE ☒ GEN RPT ☐ NONSTD PART ☐ SPEC
8. ORIGINATOR'S DOCUMENT NUMBER [redacted] AD-A032141	9. ORIGINATOR'S PART NAME/IDENTIFICATION N/A	
10. DOCUMENT (SUPERSEDES) (SUPPLEMENTS) ACCESS NO. None	11. ENVIRONMENTAL EXPOSURE CODES N/A	
12. MANUFACTURER N/A	13. MANUFACTURER PART NUMBER ----	14. INDUSTRY/GOVERNMENT STANDARD NUMBER

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This report

Describes a program for the development of design, acceptance and test criteria for helicopter transparent enclosures. In addition, a comprehensive Helicopter Transparent Enclosures Design Handbook will be prepared. The effort is being accomplished in three major tasks:

(1) Establishment of Preliminary Criteria; (2) Verification of Criteria by Analysis and Test; (3) Preparation of Design Handbook.

In general, criteria shall be substantiated by published data and historical acceptance. Where no criteria, or where conflicting criteria exist, analysis and tests are being performed. Emphasis is placed on structural substantiation methods and the airframe/transparency interface.

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Aircraft; Windshield; Canopy; Transparencies; Helicopter; Design Criteria; Guidelines; Testing; (Doc Des--P)

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INTRODUCTION

Helicopter transparencies have a relatively poor service record and represent an exceptionally high percentage of airframe maintenance costs. Some of the more plausible reasons why are: (1) Helicopter transparency requirements have just recently become sophisticated and consequently, transparency expertise remains principally fixed-wing oriented; and (2) Because of their complexity, helicopter development is concentrated on dynamic systems, thereby limiting the scope and vigor of helicopter transparency R&D pursuits.

The Army, recognizing these deficiencies, funded two parallel studies conducted by PPG Industries and Goodyear Aerospace Corporation to document the scope of the problem, and recommend action in the form of design, test and acceptance criteria. Results of these studies, published in USAAMRDL Technical Reports TR 73-19[1] and TR 73-65[2], show that windshields are a major source of airframe damage - particularly heated windshields. Some heated windshields have a Mean Time Between Failure (MTBF) as low as 200-300 hours. Furthermore, many scratches, pits, scores, and overall optically degraded transparencies are "lived with" in the field. Thus, the reported time between removals is artificially higher than warranted. Some of these deficiencies persist well after the helicopter has been put into service. These studies also pointed out that for a given type or class of helicopter, there is no generally accepted method for ranking the relative importance of transparency characteristics leading to an effective trade-off of the many conflicting requirements. The necessity for a major effort to develop design, test and acceptance criteria for helicopter transparent enclosures is evident.

The Eustis Directorate, USAMMRDL awarded a contract in June of 1974 to Sikorsky Aircraft which is intended to establish validated design, acceptance and test criteria based upon additional research and extensive laboratory and analytical studies. Emphasis is being placed on structural substantiation methods and the airframe transparency interface. A comprehensive Design Handbook for Helicopter Transparent Enclosures will also be produced as a product of the work performed in this program. The effort is being accomplished in three major tasks:

* Establishment of Preliminary Criteria
* Verification of Criteria by Analysis and Test
* Preparation of Design Handbook

This paper is, in effect, an interim report on some of the noteworthy results achieved to date. The program final report and Design Handbook are scheduled for release during the latter part of 1976.

Some of the specific tasks that have been completed or are in progress are described in this paper.

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Structural Endurance Tests

Existing structural qualification tests are not comprehensive enough to support high MTBF's. In order to formulate meaningful qualification tests for transparencies, the magnitude as well as frequency of occurrence for all loading conditions must be known This total loading environment for helicopters must include the effects of aerodynamic pressure, maneuvers and gust loads, temperature, humidity and vibration, all of which may be coupled to various degrees.

Helicopter operations are essentially conducted at low altitude where local geographic weather conditions prevail. This means that undue conservatism would result if extreme MIL-SPEC environments (-65°F or +160°F) were assumed to occur continuously and simultaneously with all structural loading conditions. To establish more realistic conditions, actual worldwide climatic variations[3] were reviewed and typical climates were analyzed.

From this analysis, two idealized climates were conservatively created to represent a hot climate and a cold climate for structural endurance testing. Tables I and II summarize this effort. High temperature (160°F) exposure is omitted from the hot-climate tabulation because it is not representative of flight conditions, but only ground or storage conditions.

TABLE I

Cold Climate Temperature Distribution

Temperature	Percent of Time
+40°F	45%
+25°F	25%
-25°F	25%
-65°F	5%

TABLE II

Hot Climate Temperature Distribution

Temperature	Percent of Time
100°F	95%
125°F	5%

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Similarly, the ground - air-ground spectrum for helicopters cannot be based on maximum pressure loading alone as commonly accepted for fixed-wing aircraft because such conditions are encountered only during infrequent high-speed maneuvers. The utility helicopter mission profile was analyzed as a case study to determine what a typical helicopter usage spectrum might look like. The ground - air-ground (GAG) cycle was derived from criteria calling for four flights per hour, coupled conservatively with the 20,000 peak load occurrences per 5000 flight hours. Table III shows the results of this analysis.

TABLE III

Typical Utility Helicopter Usage Spectrum

Load Factor	Velocity	Vibration	Pressure	Percent Time
1.0 g	V max	0.8 g	1 psi	5%
2.25 g	1.1 V_{cruise}	0.6 g	0.75 psi	5%
1.5 g	1.1 V_{cruise}	0.4 g	0.62 psi	90%

The criteria developed for the utility helicopter is being used in instrumented structural/environmental tests designed to quantitatively show the effects and interaction of complex loading conditions that affect the life of a windshield. The basic hypothesis is that once the cause of failure can be isolated and studied under controlled conditions, improvements can be developed that will extend service life. Proof of this concept for fixed wing aircraft transparencies has been established in References 4 and 5.

NASTRAN Finite Element Analysis

The expansive transparent areas found on most helicopters offer potentially significant savings in weight when thicknesses are minimized. In order to achieve this objective, while maintaining structural integrity, the magnitude of the design operating stresses in the transparent enclosure must be reliably known. Conventional "hand" methods of rigid body stress analysis have significant deficiencies when applied to typical helicopter transparencies. A more accurate approach is to use a finite element analysis.

Also, in the past, canopies for helicopters have been considered secondary structure, and analyzed only for local airloads and inertia loads. Influence on overall cockpit bending was assumed negligible, and usually ignored during structural analysis. However, since canopies are rigidly fastened to the primary structure, secondary loads can be induced as a result of primary structure deflections from application of flight loads.

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NASTRAN can be used to determine; (1) The amount of fuselage wracking that can occur during accelerating maneuvers; and (2) The effect on windshield stress.

Case Study

A Sikorsky YUH-60A UTTAS (Utility Tactical Transport Aircraft System) nose section was used as a model for a case study. UTTAS represents the newest generation of Army helicopters, has relatively large windshields supported by slender posts (Figure 1), and is subjected to high aerodynamic pressure and maneuver loads.

Figure 1. Sikorsky YUH-60A UTTAS Helicopter.

Specific factors investigated in the NASTRAN analysis were:

* Effect of fuselage deformation on windshield stress
* Interaction between membrane and bending stresses due to transparency curvature
* Effects of elastic supports on windshield stress
* Effects of large displacements on analytical accuracy

NASTRAN Model Description

Two NASTRAN models were constructed which varied in size and degree of refinement. The basic model contained the upper cockpit, windshields, lower cockpit and forward cabin. The windshield model was composed of 200 TRIA1 triangular plate bending elements having six degrees of freedom. TRIA1 is a triangular plate bending element which allows for independent specification of membrane and bending properties. The basic model is shown in Figure 2.

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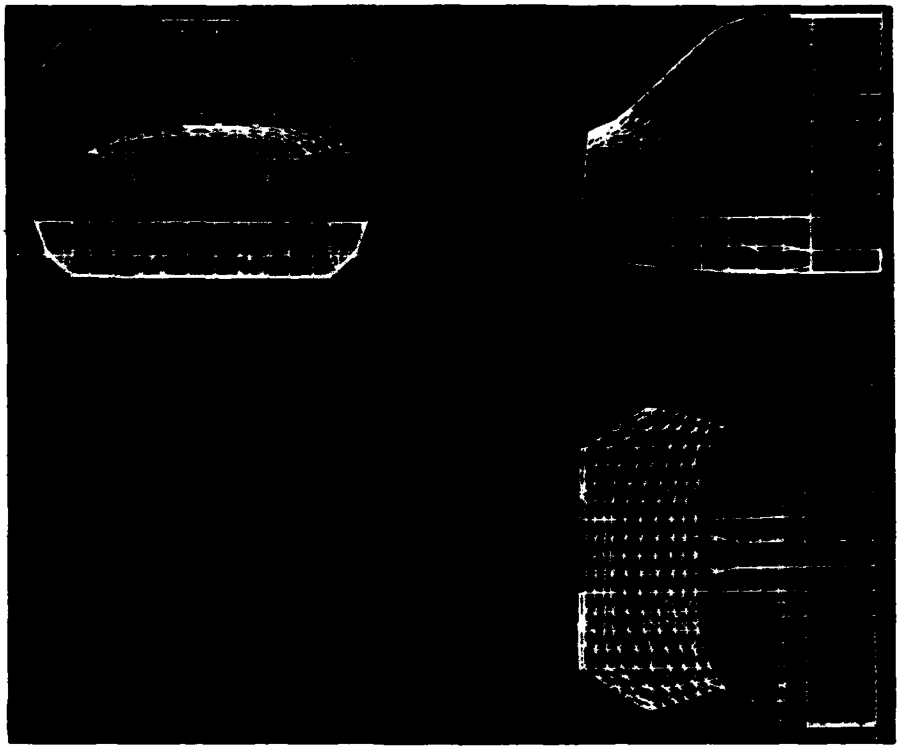

Figure 2. NASTRAN Model of YUH-60A Nose Section.

The second model, identical in all respects to the basic model except for omission of windshields, was constructed to obtain displacements of the windshield support structure from inertia loading.

Three different laminated windshields were modeled; glass/glass, glass/acrylic, and acrylic/polyester. All were idealized as monolithic structures.

DISCUSSION OF RESULTS

Effects of Fuselage Deformation on Windshield Stress

To evaluate the effects of fuselage deformation on windshield stress, an inertial loading condition representative of a symmetrical pullout maneuver was analyzed using the NASTRAN model, with and without the windshields installed. This condition produced critical down bending loads in the area of the cockpit.

First, the analysis was performed on the model without the windshields. The results of this analysis showed that the displacements that occur during maneuvers are significant. Figure 3 is a profile view of the center post deflected shape. Note that the post has a maximum camber of approximately 1/16 inch. Since the post is stiffer than the windshield, this camber will induce windshield stresses.

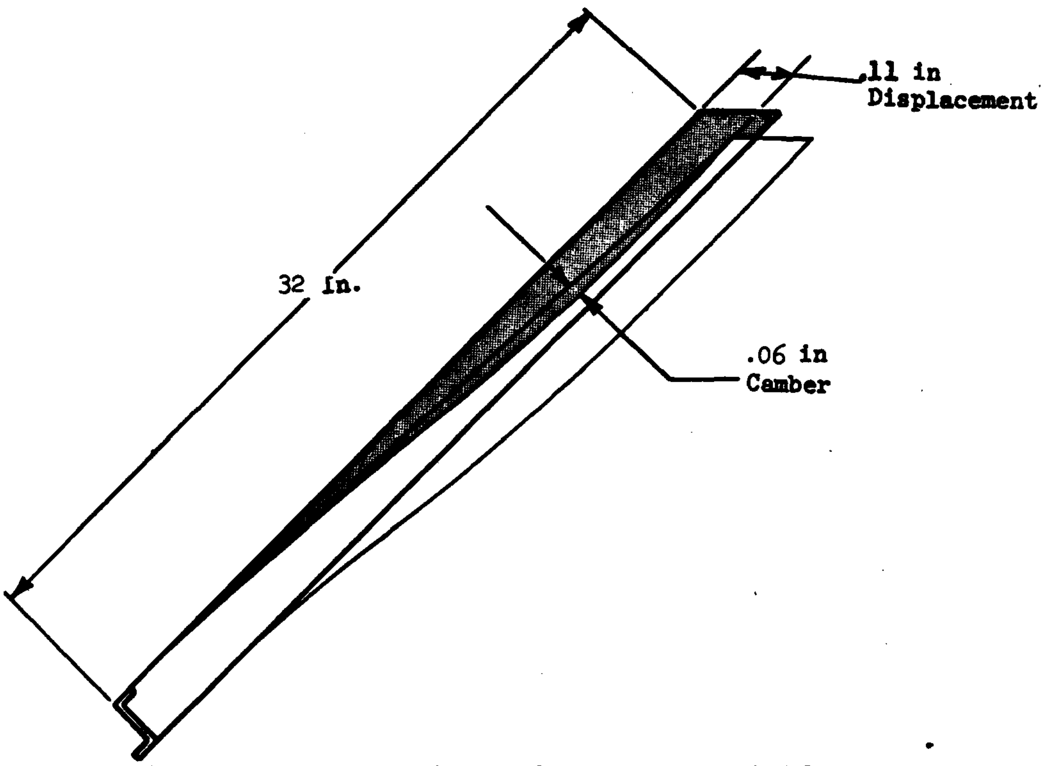

Figure 3. Deflection Mode for Windshield Post.

Figure 4 shows the deformed outboard windshield structure superimposed on the undeformed shape. This illustration shows graphically how fuselage wracking can warp and twist windshields. Most windshields are mounted with a certain degree of flexibility via oversized mounting holes and gaskets. However, for the conditions analyzed, the displacements were large, and would not be absorbed by normal edge attachment flexibility.

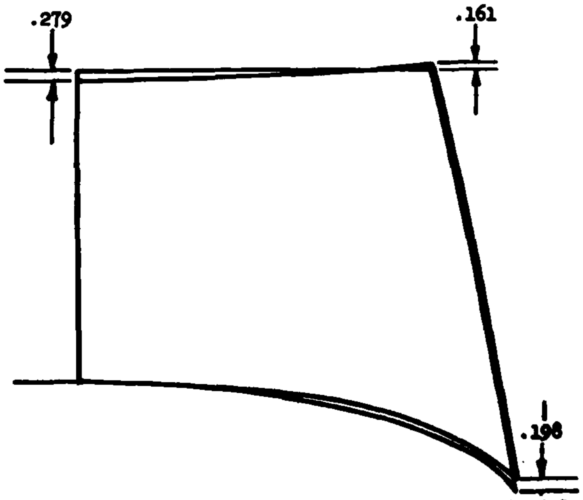

Figure 4. Deformed Shape of Windshield Cavity.

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In the NASTRAN model which assumed the windshield installed maximum tensile stresses in the windshield were calculated to be approximately 2000 psi. The semi-tempered soda-lime glass commonly used in windshields has an abraded strength of approximately 6500 psi, therefore, stresses from fuselage wracking cannot be considered negligible.

The distribution of in-plane windshield forces normal to the center posts is plotted in Figure 5. This distribution is indicative of how cockpit deflections induced in-plane bending loads into the windshields.

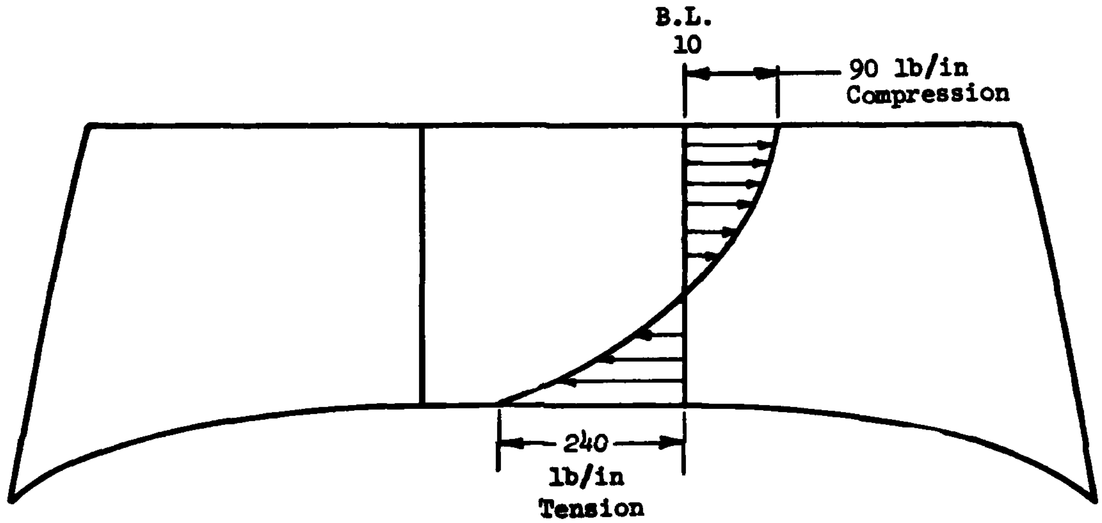

Figure 5. In-Plane Forces Normal to B.L. 10 Post Vertical Bending Condition.

Effects of Transparency Curvature on Windshield Stress

Many helicopter cockpit transparency shapes have second degree curvature, either compound or conic. When subjected to pressure loading, these structures support loads partially by membrane action, and partially by bending. Classical handbook equations do not apply to these shapes and unique analytical solutions are required to determine stress.

It was demonstrated that NASTRAN does have the capability to analyze conic shaped structures subjected to pressure loading. This was accomplished by analyzing a typical aerodynamic pressure loading condition. A .3 psi uniform pressure, representative of cruise speed loading was used for this case. The maximum calculated stress in the center windshield was 2435 psi while the maximum stress in the outboard curved windshields were only 942 psi, despite the outboard panels having approximately twice the area of the center panel. The stresses in the outboard panels were predominantly in-plane, while the stresses in the center panel were predominantly bending.

Effect of Elastic Supports on Stress

The effects of elastic supports on windshield stresses were evaluated by performing both linear and differential stiffness analyses for several load conditions. Differential stiffness considers first order changes in geometry that occur due to deflections, while the linear analysis does not.

Comparing the results of the two methods of analysis, differential stiffness showed only slight changes for the stresses in the outboard area of the structure, but significant changes of up to 100% in the center region. This occurred because the large displacements and stresses in the center region have a greater effect on altering geometry than the small loads and displacements in the outboard region.

A typical computer generated contour plot of the transverse displacements for the center windshield under uniform pressure loading is shown in Figure 6. The total deflection is divided into 14 equal increments with each increment represented by one line. It may be observed that the maximum displacement is not at the center of the windshield, but more towards the lower sill. This is due to the bottom sill having a lower stiffness than the upper sill.

Effect of Large Displacements on Analytical Accuracy

In order for the results of the NASTRAN analysis to be valid, it is necessary that the deflections satisfy the assumptions used in thin plate theory, that the deflections remain small in comparison with the thickness of the plate.

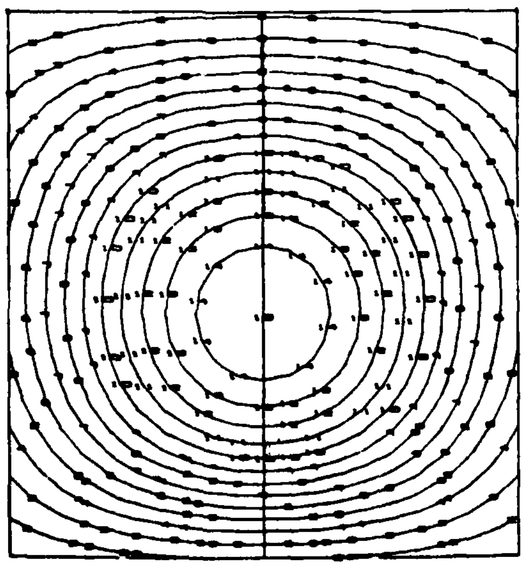

Figure 6. Computer Generated Displacement Plot for Center Windshield Under 1 PSI Loading.

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To determine when the NASTRAN analysis would become invalid, three center flat windshield configurations (glass/acrylic, acrylic/polyester, glass/glass) were analyzed for a higher pressure loading of 1 psi. For the glass/acrylic and acrylic/ polyester,windshields, the calculated deflection to thickness ratios were much greater than one (13), and the NASTRAN analysis must be considered invalid. These two flat windshield configurations support the pressure load by combined membrane-bending action which the NASTRAN program, as presently structured, cannot analyze.

For windshields where the transverse load is supported by membrane action, future work is planned to investigate the feasibility of developing a large displacement finite element program suitable for this type of structure.

The deflection to thickness ratio for the glass/glass design was 6.5, which is not unrealistic for this type of structure. The NASTRAN results are to be correlated with measured data obtained from instrumented tests performed on identical configurations.

Suitability

The NASTRAN finite element analysis was found to be suitable for the analysis of homogeneous transparencies of the following types:

1. Flat plates and curved shells where the transverse deflections are small in comparison to the thickness of the part.

2. Curved shells where the pressure loads are resisted by in-plane forces (similar to hoop tension or compressive arch).

It is not suitable for the analysis of transversely loaded flat plates where the load is carried partially or entirely by membrane effects. It is also not suitable for the analysis of unsymmetrically laminated windshields where the coupling effects from the interlayer are important, because as a practical matter, the windshields must be modeled as monolithic structures.

ABRASION TESTS

Existing field service has demonstrated that the most prevalent problem experienced with Army helicopter windshields are abrasion and resultant loss of transparency. Abrasion may be caused by windshield wiper action, impingement of sand or dust particles, and improper cleaning procedures. Figure 7 is an example of the type of damage caused by windshield wipers.

Figure 7. Windshield Wiper Abrasion.

Laboratory simulation of these conditions are required as part of component qualification so that service performance can be reasonably predicted prior to introduction to service. The series of tests described herein were conducted with this purpose in mind. Five generic materials were tested to evaluate their comparative performance. They were:

Acrylic
Hardcoated acrylic
Polycarbonate
Hardcoated polycarbonate
Glass

The pronounced effect of abrasion on transparent materials is to increase the surface haze. Haze is generally defined in terms of the percent of light scattered and therefore lost in passage through the material. To provide a frame of reference, a material with 30% haze would be considered translucent rather than transparent.

Periodic haze measurements were taken at intervals corresponding approximately to each 5% increase in haze.

The first series of tests was conducted by Swedlow, Inc., Garden Grove, California, in accordance with Sikorsky specifications. The hardcoat used was SS-6590, a proprietary abrasion resistant coating formulated by Swedlow, Inc. In addition to the five materials listed above, two sets of coated polycarbonate and acrylic specimens were also tested after artificial aging consisting of 250 hours exposure to 100% relative humidity at 160°F. Similar test conditions have shown that typical hard-coats may degrade significantly in respect to adhesion and abrasion resistance after this type environment exposure.

Apparatus and methods used to perform the dry rubbing abrasion and windshield wiper test were based on the test work conducted by Plumer, and described in Reference 6.

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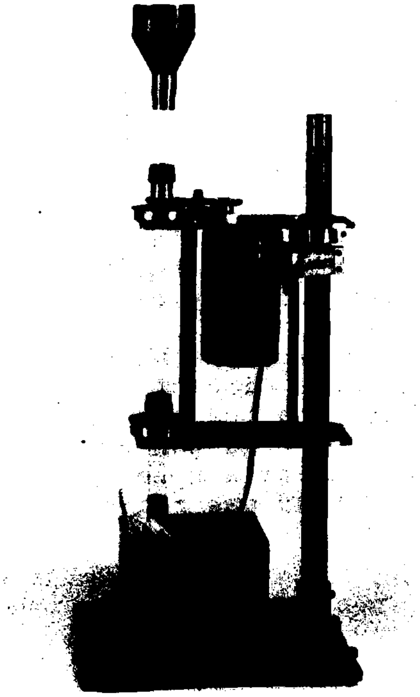

Figure 9. Apparatus for Falling Sand Test.

WINDSHIELD WIPER TEST

This test method was performed to simulate the effect of windshield wiper operation on the various transparency materials. The apparatus consisted of a specimen holding fixture mounted at approximately 45° with provisions to mount material specimens. A windshield wiper driver arm and Hycar rubber blade (30-40 Shore Hardness) attached to an aircraft type motor was also mounted to the test fixture as well as a system for regulating and discharging the abrasive slurry onto the 16 x 21 inch test specimen at 300 ml/minute rate (See Figure 10).

The slurry consisted of 1600 grams of AC Air Cleaner Test Dust (coarse) in 16 liters of water. A peristaltic pump was used to recirculate and apply the slurry, and vigorous stirring was required in the reservoir to prevent the settling out of tne abrasive. Eight points were selected on each sample according to a mask previously made which sampled the haze on the periphery of the part as well as in the middle. The windshield wiper blades were adjusted to 0.5 pounds per linear inch of blade length and operated at 100 cycles per minute. Every 12,000 cycles the windshield wiper blades were changed and additional slurry was added as required.

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DRY RUBBING ABRASION TEST

This type of abrasion test method was performed to evaluate the rubbing abrasion properties of the different materials from simulated dry wiping of dirty transparencies.

Procedure

Apparatus consisted of a reciprocating motion abrader designed to provide a wiping action that simulates conditions encountered by field cleaning of transparencies by aircraft personnel.

Prior to testing, haze measurements were obtained for all samples. A one-inch diameter disc of 100% wool felt, 1/8 inch thick cemented to the abrading head was impregnated with dry 400 grit boron carbide. The head was weighted with 500 grams of load and the test was run at a speed of approximately 50 cycles per minute. The abrading head was reimpregnated after each 25 cycle period.

Figure 8. Apparatus for Dry Rubbing Abrasion Test.

FALLING SAND TEST

This type of abrasion test method was performed in compliance with ASTM D-670-70 (except that measurement of gloss was not required) to evaluate the effect of impingement by abrasive particles. The apparatus consists of a hopper and glass tube rotating at about 7 rpm that allows a free fall of abrasive at 200 to 250 grams/minute from the fixed height of 25 inches. The test specimen is 3 x 6 inches and is held at 45° position to the fall of abrasive particles (See Figure 9).

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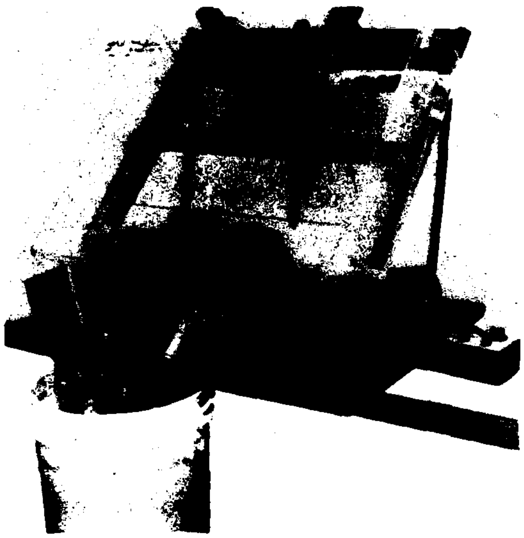

Figure 10. Windshield Wiper Test Apparatus.

The second series of tests was conducted by Gentex Corporation, Carbondale, Pennsylvania, in accordance with Sikorsky specifications. The hardcoat used was 5 microns of Abcite coating (Trademark E.I. DuPont DeNemours and Company). A blowing sand and dust test using MIL-STD-810B, Method 510, with airflow set at 3500 fpm, was attempted, but after 24 hours of testing, all specimens were unaffected and showed no change in initial haze measurements. Sand used for this test was too fine and powdery.

WET RUBBING ABRASION TEST

This test method was performed to simulate the effects of wiping dirty wet windshields, wherein the dirt contains abrasive particles. The specimens were mounted on a turntable and rotated at 10 rpm while continually applying a slurry of water and fine sand through a three-inch tube placed vertically over the specimen as shown in Figure 11.

One sample at a time was mounted in the center of the turntable. The center of the three-inch tube was offset 1-1/2 inches from the center of the specimen. This allowed full abrasion over the entire area of the specimen. A piece of foam rubber which was wrapped around and fastened to the bottom of the slurry tube rested on the specimen during the test. This simulated a wiping effect duplicating actual service conditions and also produced more consistent and uniform haze measurements. A one-pound per square inch constant pressure was obtained by using a 17-inch long tube and keeping the slurry above 15 inches.

Figure 11. Apparatus for Slurry Abrasion Test.

Consistency of Test Data

Five specimens of each material were used in each test to evaluate consistency of results for the test method. Scatter of test measurements for the dry rubbing abrasion test and falling sand test was minimal, with deviation of no more than 3% haze from the average measured values. Consistency of measurements for the slurry rubbing abrasion test was not as good, and deviations greater than 11% haze were observed, with the average deviation being approximately 5% haze.

Considerable variation in measurements occurred during the windshield wiper test. Fluctuations in readings of over 10% haze were noted for measurements taken from the same specimen, and also from specimen to specimen. Some of the factors causing the variability are inherent to the type of abrasion, and others are related to the characteristics of the wiper blade, flatness of the test specimen, and wetting action of the abrasive slurry on different substrates.

RESULTS

The tests showed that the tolerance to abrasion of uncoated acrylic or polycarbonate material is very poor as measured by the falling sand, rubbing abrasion and windshield wiper tests that were conducted. The application of hard coats to acrylic and polycarbonate glazing material imparts a significant increase in the tolerance to abrasion as indicated by the test results. The effect of artificial aging, 250 hours exposure to 100% humidity at 160°F environment was found to severely degrade adhesion of the SS-6590 hardcoat to the polycarbonate substrate. Marginal

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adhesion of unaged SS-6590 hardcoat to polycarbonate was also noted during the windshield wiper test. Glass material was found to be vastly superior to the hardcoated materials during the rubbing abrasion and windshield wiper tests, but not as good as the hardcoated materials when subjected to the falling sand impingement tests.

A summary of the results of all four abrasion tests is presented in Table IV. Windshield wiper test results are shown in Figure 12.

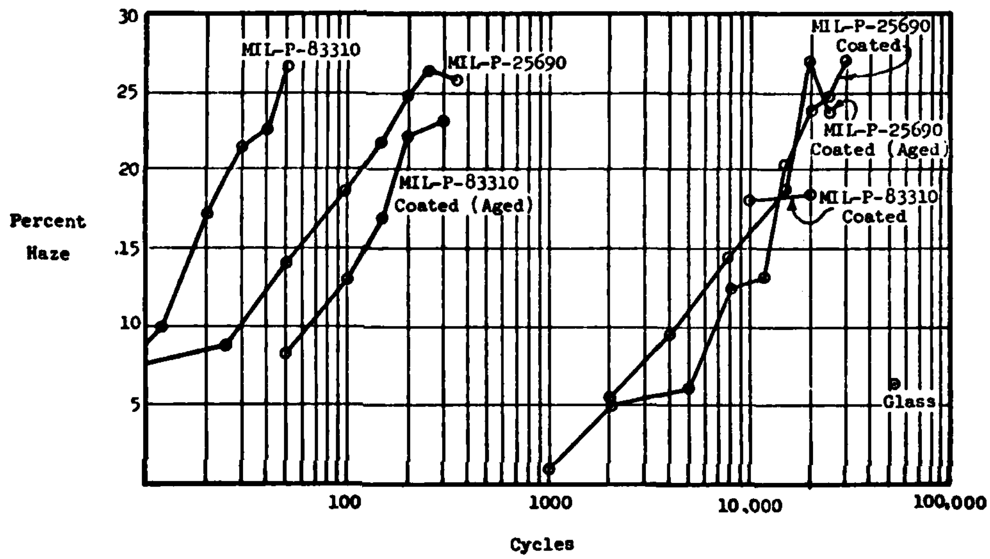

Figure 12. Windshield Wiper Test Results.

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TABLE IV

Summary of Abrasion Test Results

Material	Falling* Sand	Dry** Rubbing Abrasion	Slurry** Rubbing Abrasion (30% haze)	Wind-** shield Wiper
	Test			
Polycarbonate	110 gm	15-27%	60	50-30%
Polycarbonate (Hardcoated)	5500	600-11%	750	50,000-25%
Aged Polycarbonate (Hardcoated)	7500	500-10%	---	500-30%
Acrylic	190	24-30%	70	350-30%
Acrylic (Hardcoated)	6500	1500-14%	200	25,000-25%
Aged Acrylic (Hardcoated)	7500	1500-11%	---	25,000-25%
Glass	1300	1500-1.5%	3600	50,000-5%

* Grams of sand required to produce 30% haze.
** Average number of test cycles or revolutions to produce the percent of haze listed.

It should be noted that the intent of this task was only to develop means to predict the performance of transparent materials when exposed to abrasive environments, and not to select materials for that purpose. Accordingly, complete qualification testing was not implemented for the hardcoats. Prior to production commitments for any hardcoated plastics, it is recommended that thorough qualification testing be performed. This would include, in addition to the tests described previously, rigorous environmental testing.

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CORRELATION OF TEST RESULTS

A realistic correlation between the test methods for rubbing abrasion and windshield wiper abrasion can be made with actual service experience. For example, several cycles of windshield wiper operation on dry or dirty acrylic helicopter windshields will have immediate effect in producing objectionable haze. The windshield wiper test performed, duplicated this condition by increasing the original haze level in stretched acrylic by 5% after only 25 cycles of operation. Likewise, the dry rubbing abrasion tests produced an increase in haze of 8% after only 3 cycles and the slurry abrasion test produced 12% haze after 10 cycles on stretched acrylic, which is representative of the damage produced by wiping plastic transparencies with dirty rags.

Correlation of the falling sand test to actual service experience is a bit more difficult, because this failure mode is rare in comparison to the other forms of abrasion. However, some estimation of the severity of the test can be obtained by calculating the flux of the impinging sand particles and comparing it to Army specifications for density of blowing sand which is 0.1 gm/ft^3. Using this approach, 1 gm of falling sand can be roughly equated to 4 minutes exposure to blowing sand at 11 ft/sec or 7.5 mph.

An increase in haze of 10% was measured for the stretched acrylic material after exposure to 50 gm of falling sand, which might be likened to 3 hours exposure to dense blowing sand. When one considers that sand storms can induce higher impingement velocities, notwithstanding flight through the storm, the potential hazard from impinging sand can be fully appreciated. Note that the kinetic energy of the impinging particles is proportional to the square of their velocities. It is felt that the reason impingement abrasion damage to helicopter transparencies has not been documented as a serious problem is that there has been only minimal exposure to conducive environments.

DESIGN HANDBOOK

The Design Handbook being prepared at the conclusion of this program is intended to be a single source technical document covering the important aspects of helicopter transparency engineering. It will be easy to read for design engineers, specialists, and non-technical personnel, and will contain liberal use of tables, charts and illustrations.

The Design Handbook will include a General Specification that will consolidate and standardize design, acceptance and test criteria for all types of transparencies used on helicopters. A rationale for the specification will be included in the Design Handbook along with guidelines for performing tradeoffs.

While the handbook is intended to be comprehensive in subject matter, it is not intended to supersede unabridged references

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such as MIL-HDBK-17A, "Plastics for Aerospace Vehicles, Part II, Transparent Glazing Materials," but instead will complement and make reference to such documents. Here the emphasis will be on design, rather than material properties.

Although a comprehensive literature survey has been conducted, any additional non-proprietary material from interested parties would still be welcome and considered for inclusion in the Design Handbook. All such material would be gratefully acknowledged. Material should be mailed to:

Sikorsky Aircraft Division
United Technologies Corporation
North Main Street
Stratford, Connecticut 06602
Attention: Bruce F. Kay,
Aircraft Design & Development

CONCLUSIONS

1. Stresses due to airframe deflections can be significant and must be accounted for in windshield design. Advanced analytical tools such as NASTRAN must be used to determine the magnitude of such stresses. In addition, the NASTRAN analysis can be used to analyze irregular shapes and transparencies mounted on elastic supports.

2. Meaningful abrasion tests have been developed which can be used to predict performance of transparent materials exposed to abrasive environments.

3. Realistic endurance test criteria has been developed which will lead to greatly improved service lives for helicopter heated windshields.

4. Final program output will provide:

   a. A uniform specification for design, acceptance and test criteria.
   b. Single source comprehensive design handbook for reference, planning, and design and development of future helicopters.

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